Precise Barriers and Shell Effects: a New Inroad to Fission Saddle Point Spectroscopy [1]

L. Phair, L. G. Moretto, D. Breus, J. B. Elliott, and G. J. Wozniak

Fission excitation functions have been measured separately for a chain of neighboring compound nuclei, from ^{207}Po to ^{212}Po via the reaction $^{3,4}He+^{204,206,207,208}$Pb at beam energies of 20-140 MeV. We present a new analysis which provides values of fission barriers and ground state shell effects with nearly spectroscopic accuracy.

To determine the fission probability, we use standard transition state theory to calculate the fission width Γ_f. The ratio of Γ_f/Γ_n is proportional to

$$\frac{\Gamma_f}{\Gamma_n} \propto \frac{\rho_f(E - B_f - E_r^s)}{\rho_d(E - B_n - E_r^{gs})} \tag{1}$$

where B_f is the fission barrier, B_n is the n binding energy, E_r^s and E_r^{gs} denote the rotational energies at the saddle point and the ground state, respectively.

For the daughter nucleus, ρ_d takes the asymptotic form: $\rho_d \propto \exp\left(2\sqrt{a_d(E - B_n - E_r^{gs} + \Delta_{\rm shell}^{n-1})}\right)$, where $\Delta_{\rm shell}^{n-1}$ is the ground state shell effect after neutron emission. The shell correction at the saddle is assumed to be zero. The inclusion of pairing at the saddle and the ground state is described in [1]. We further assume that the fission barrier has two parts: $B_f = B_{\rm macro} - \Delta_{\rm shell}$. For the macroscopic part we take a scaled value of the Thomas-Fermi predictions [2].

The expression for Γ_f/Γ_n has four free parameters: $B_{\rm macro}$, $\Delta_{\rm shell}$ of the compound system, $\Delta_{\rm shell}^{n-1}$ of the 1 neutron out daughter nucleus, and the ratio a_f/a_d. To use this description of Γ_f/Γ_n, we write the total fission cross section as

$$\sigma_f = \sum_{i=0} \sigma_f^{(i)} = \sum_{l=0}^{l=l_{\rm max}} \sum_{i=0} \sigma_l P_f^{(i)}(E, l) \tag{2}$$

where $\sigma_f^{(i)}$ is the fission cross section after i neutrons are emitted, σ_l is the angular momentum distribution of the fusion cross section ($(2l+1)\pi\lambda\!\!\!^{-2}$), $l_{\rm max}$ comes from the fusion cross sections, and $P_f^{(i)}(E, l)$ is the fission probability after the emission of i neutrons from a compound nucleus of initial angular momentum l and initial energy E. The fission probability at each "step" i is

$$P_f^{(i)}(E, l) = \frac{1}{1 + \frac{\Gamma_n}{\Gamma_f}(E, l, i)}. \tag{3}$$

With Eqs. (1)-(3), we are prepared to fit the neighboring Po compound nucleus fission cross sections. The fits are very good and shown in [1]. The extracted $\Delta_{\rm shell}$ values are shown by the solid circles in Fig. 1. They show a clear shell closure at $A = 210$ ($N = 126$). Furthermore, there is a remarkable agreement between the values from the present fission analysis and those determined by Möller *et al.* in fitting the ground state masses [3] (open circles). The mean deviations are smaller than 200 keV.

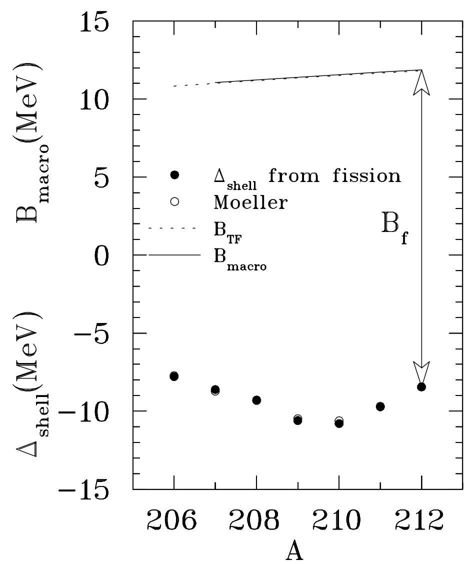

FIG. 1: $\Delta_{\rm shell}$ extracted from the fission fits (solid circles) are plotted as a function of mass number. The open circles represent the $\Delta_{\rm shell}$ estimated by Möller *et al.* [3]. The solid line is the macroscopic barrier extracted from the fission fit and the dashed line is a Thomas-Fermi estimate [2]. The difference between $B_{\rm macro}$ and $\Delta_{\rm shell}$ is the fission barrier B_f.

The extracted fission barriers are shown in Fig. 1 as a difference between the shell correction and the macroscopic barriers. The macroscopic barrier from the fit is given by the solid line and is nearly indistinguishable from the Thomas-Fermi prediction (solid line) [2].

This analysis gives an order of magnitude improvement in accuracy compared to earlier results [4] and may lead to a future detailed exploration of the saddle mass surface and its spectroscopy.

[1] Condensed from LBNL-51709, (2002).
[2] W.D. Myers and W.J. Swiatecki, Phys. Rev. C **60**, 4606 (1999).
[3] P. Möller, *et al.*, At. Data Nucl. Data Tab. **59**, 185 (1995).
[4] L.G. Moretto, *et al.*, Phys. Rev. Lett. **75**, 4186 (1995).